A 3D potential field model of the Pilanesberg Complex shape and structure.

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ABSTRACT

The Mesoproterozoic Pilanesberg Complex, South Africa, is the world's largest alkaline intrusion. While surface field relationships suggest an inward dipping structure, it is unclear how these dips extend to depth. The 3D geometry of the Pilanesberg Complex is also unknown. 2D and 3D forward and inversion modelling of gravity and magnetic data are used to set limits on the 3D shape of the Complex.
Based on age and chemical affinity, it is known that the Pilanesberg Complex forms part of a larger system of alkaline intrusions that includes two dyke swarms that radiate to the north-west and south of the Complex, as well as smaller circular clinopyroxene intrusions throughout the Bushveld Complex.
The Pilanesberg dyke swarms and the circular clinopyroxenite intrusions are reversely magnetised to that of the normally magnetised Pilanesberg Complex, suggesting that a magnetic reversal occurred during emplacement of the system.

Key words: Pilanesberg Complex, 3D modelling, ring dyke, magnetic reversal

INTRODUCTION

The Pilanesberg Complex, with a diameter of 28 km, is the world's largest alkaline intrusion (Figure 1). The intrusion is located on the Kaapvaal Craton within the gabbro-norite of the Rustenburg Layered Suite and red granite of the Lebowa Granite Suite on the western limb of the Bushveld Complex, South Africa (Hansen et al., 2006). The Pilanesberg Complex intruded between 1200 and 1450 Ma during the Mesoproterozoic era during an intraplate extension event. The Pilanesberg pyroclastic and lava flow sequences resulted in an inward dipping structure around a preserved central core and plug (Olivo and Williams-Jones, 1999; Michell and Liferovich, 2006., Cawthorn et al., 2006).

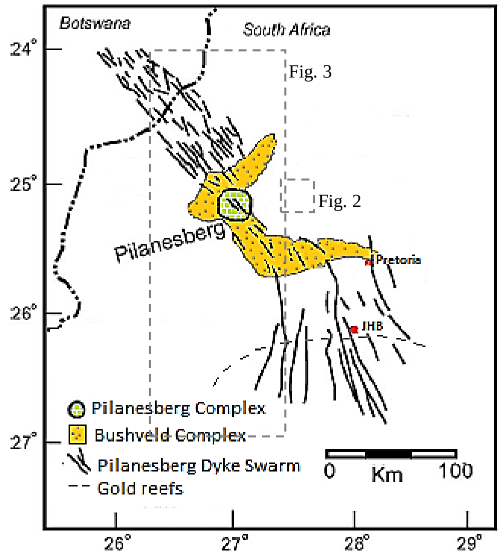

Figure 1. Regional setting of the Pilanesberg Complex and dyke swarms with the western Bushveld complex, modified from Emerman (1991), Cawthorn (2006).

The Pilanesberg Complex is associated with a number of other intrusions including the compositionally associated Pilanesberg syenite dykes (Figure 1). Recent work by Cawthorn et al. (2012) reveals circular intrusions of clinopyroxene approximately 8 km wide in the middle of the Bushveld Complex (Figure 2) with an age of 1207 ± 200 Ma. The intrusions have a compositional affinity to alkaline intrusions similar to Phalabora and are thus proposed to be related to the Pilanesberg system (Cawthorn et al., 2012).

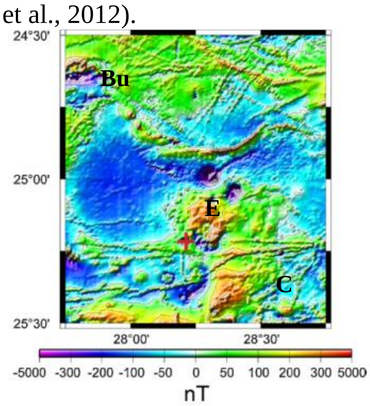

Figure 2. Occurrence of circular intrusions related to the Pilanesberg Complex. Bu-buffelskraal, E-Elandskraal, C-Cullinan kimberlite (Cawthorn et al., 2012)

One swarm of syenite dykes extends in a north-westerly direction into Botswana. The second swarm, oriented north-south, can be traced by composition and by magnetic correlation to the south of the Complex and into the Johannesburg Dome (Emerman, 1991).

The dyke swarms are named as Pilanesberg dykes from the comparable compositions as well as the similar age range with the Pilanesberg Complex (Cawthorn et al, 2012). However, the airborne magnetic data pertaining to the dykes shows strong negative anomalies, opposite to that of the Complex itself (Figure 3). The intrusion of the dykes in a parallel orientation is due to a series of normal faults that are directly related to extensional tectonics and alkaline magmatism (Hansen et al., 2006).

The composition of the Pilanesberg dykes are generally tholeiitic but includes the composite dolerite-syenite dykes 225 km south of the Complex, exposed in mines along the gold reef (Figure 1), as well as the more common syenite dykes occurring across most of the dyke swarm. A strong iso-remnant magnetisation component is recorded from lightning strikes on surface outcrop, thus rock samples are collected from deep mines or quarries to avoid the surface effect. Gough (1958) examined five Pilanesberg-aged dykes south of the Complex using palaeomagnetism, and concluded that the dykes carried remnant magnetisation. The samples from the Central Rand gold mines indicated a correlating mean direction for the north-seeking magnetic pole (Gough, 1958). Dykes sampled include the composite dykes (syenite encased in dolerite), from Libanon and Venterspost Gold Mines, the basic dykes at Robinson Deep and East Geduld Gold Mines and a syenite dyke at the Simmer and Jack Gold Mine.

The north and south dyke swarms were correlated by a double peak reversed anomaly that has secondary highs to the south with the remnant inclination of +69.3 ° and remnant declination of 24 ° (Gough, 1958. Emerman, 1991). This double peaked magnetic anomaly is due to a two staged emplacement dated at 1310 ± 60 Ma (Emerman, 1991), where by the dolerite dykes were intruded by a syenite dyke before the package cooled, forming a composite dyke with a syenite centre surrounded by dolerite (Emerman, 1991).

Airborne magnetic data over South Africa shows that the Pilanesberg Complex carries a strong induced magnetisation that produces an anomaly with amplitude of 325 nT (with respect to the 150 m flight height) above the background magnetic signature of the country rock into which it intruded. The compositionally associated Pilanesberg dykes are remanently magnetized and have a negative magnetic anomaly of 315 nT with respect to the survey flight height of 150 m (Figure 3). The Pilanesberg Complex does not show a well defined dipole, suggesting that it carries some remnant magnetisation, unless the Pilanesberg dipole low is interfering with the strong low of the western Bushveld Comple.

Dating the Complex is problematic because although the rocks contain abundant Zr, this element is mainly caused by Eudialyte rather than zircon. Eudialyte is not retentive of radiogenic Pb, and thus not suitable for geochronology (Olivo and Williams-Jines, 1999).

Ages of the Complex itself includes 1260 ± 50 Ma (K-Ar, Olivo and Williams-Jones, 1999) and 1397 ± 47 Ma (U-Pb on titanate, Hansen et al., 2006). These ages are considerably different, and are of poor precision. Therefore, the age of emplacement of the Complex is not well constrained (Cawthorn et al., 2006). Ages for the Pilanesberg Dykes range from 1290 ± 80 Ma, 1302 ± 80 Ma, 1310 ± 80 Ma (Robynson Dyke) and 1330 ± 80 Ma (Gemspost, Venterspost Mine) (All from Rb-Sr on biotite, Van Niekerk, 1962., Emerman, 1991) which fall within the range of ages obtained for the Complex itself (Hansen et al., 2006). Clinopyroxenites recovered from drill cores in the central Bushveld Complex yield 1207 ± 200 Ma (Sm-Nd mineral isochron, ref) and 1341 ± 37 Ma at Spitskop further east (Cawthorn et al., 2012).

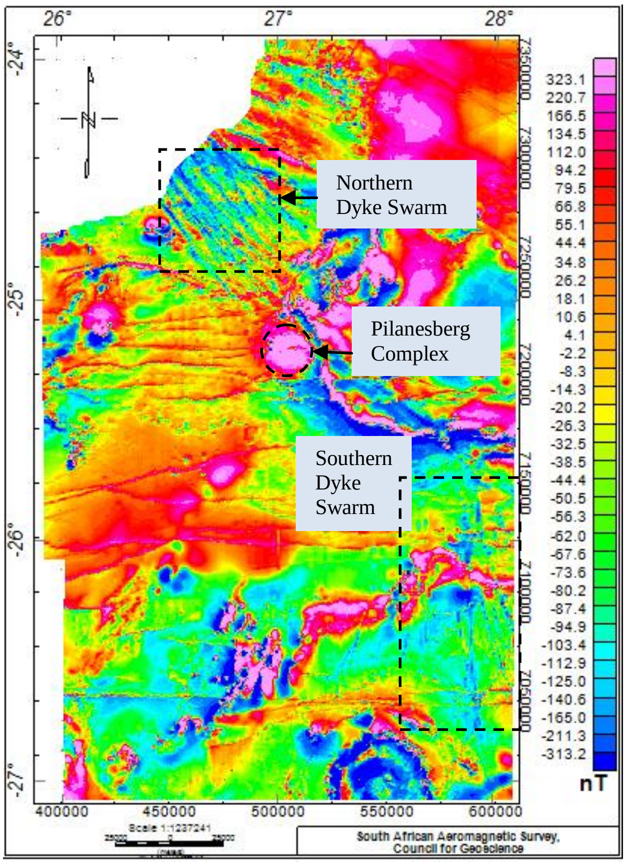

Figure 3. Magnetic data indicating the signature of the Pilanesberg Complex (positive 325 nT signature) and that of the Pilanesberg dykes (negative 315 nT signature) seen in blue, 1:50 000 magnetic maps of South Africa 2426, 2526, 2626 (Council for Geoscience,)

The age data on the Alkaline Province helps to constrain the emplacement range of the Complex, which is believed to have intruded from the outer ring to the central plug in several stages around the time that magnetic reversal and the dyke swarms intruded. This is examined from existing structural geology and potential field modelling.

Geometry of the Pilanesberg Complex

The geometry of the Pilanesberg Complex at depth has been suggested to be a series of ring dykes or alternately cone sheets that were emplaced horizontally and followed by centripetal subsidence (Cawthorn, 2009; Lurie, 1986).

Cawthorn (2009) proposed several models to account for the space required for the 28 km^2 intrusion of the Pilanesberg Complex and how the host rock would accommodate it. The examples in Figure 4 show that the host rock shifts according to the geometry and manner of intrusion. No depth scale is represented.

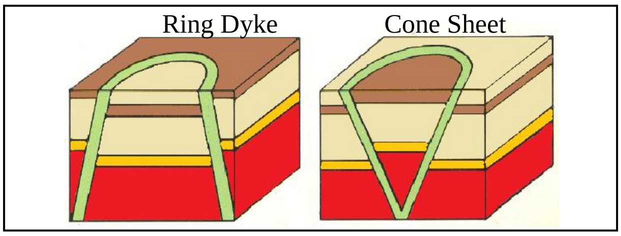

Figure 4. Two possible geometries to explain the host rock space problem for the intrusion of the Pilanesberg Complex. A ring dyke would form either with subsidence of the host rock (left), or the formation of a cone sheet (right), modified from Cawthorn (2009).

Lurie (1986) has proposed a geological model of the Pilanesberg Complex using the dip of the volcanic rocks from surface observation (Figure 5). The model shows a cone formed by inward-dipping ring dykes around a central plug with the vertical axis leaning to the southeast. Lurie (1986) describes the Complex as being composed of an inward dipping ring structure around a central plug, with large faulted blocks resulting from a collapsed caldera formation with approximate angles of 35° in the south, to 50° in the west, and 45° in the east. The rocks in the north, however, appear to dip at a 35° angle towards the north (Figure 5).

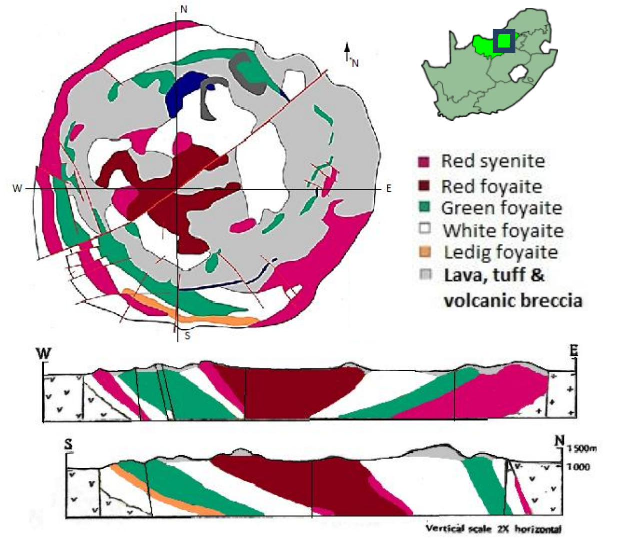

Figure 5. A schematic representation of the geology of the Pilanesberg Complex, modified from Lurie (1986), Cawthorn et al. (2006).

A negative density contrast exists between the Pilanesberg Complex and the Bushveld Complex granite on the national gravity grid (Figure 6). This allows gravity modelling to test the shape of the Complex below the surface relationships. The data also shows a change in the gravity signal within the ring structure, that may allow for modelling of the Complex's internal structure.

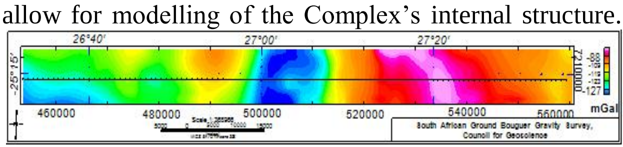

Figure 6. West East Bouguer Gravity Profile over the Pilanesberg complex (Blue) and the Bushveld Complex (Red)

METHOD AND RESULTS

The unknown shape of the Pilanesberg Complex below the measured surface relationship is tested using gravity data over the area. From Lurie 1986 it is known that the internal structure dips inward which is conceptualised using the west-east profiles through the middle of the Pilanesberg Complex. The 2D profile models (Figure 7) investigates how the shape of the Complex relates to the calculated field (from Figure 6) based on the concept and the data in Figure 4 and 5 respectively.

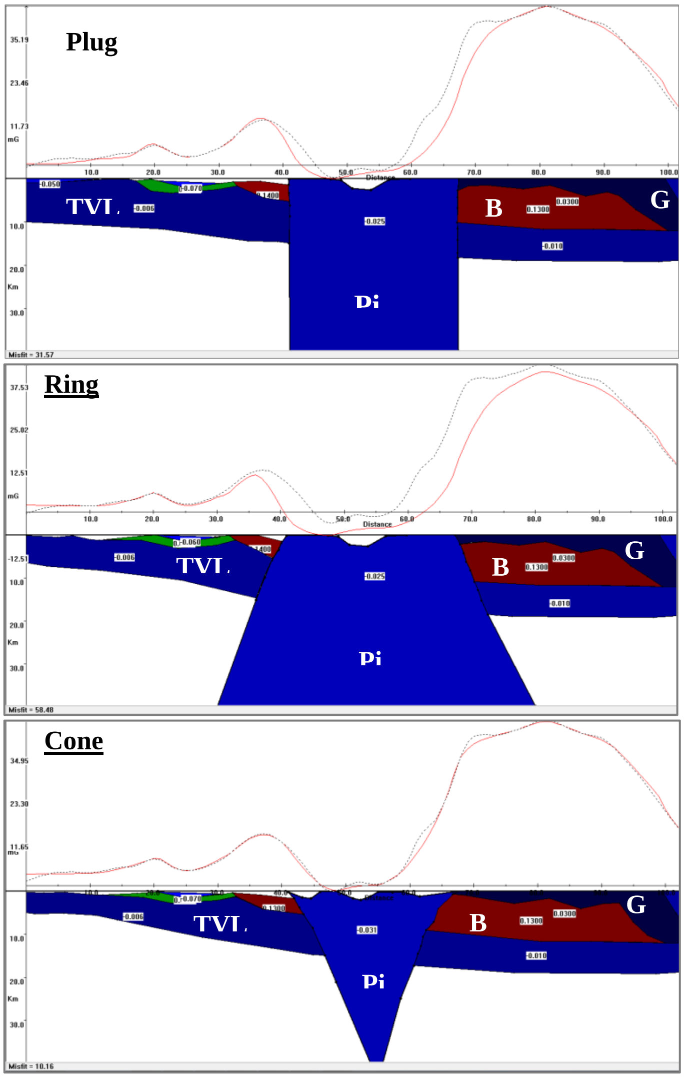

Figure 7. Preliminary modelling of the 2D west-east Pilanesberg (Pi) profiles from figure 4 with surface geology correlations to the host rock.
(A) Vertical contact model- a poor fit to the field data.
(B) Outward dipping Complex- worse fit than the plug model; however the inward dipping model in C) is able to match the gravity data better.
TVL-Transvaal, Magaliesburg quartzite (green), B-Western Bushveld complex, G- granite.

Modelling of the west-east profile over the Pilanesberg Complex indicates that a body with vertical or outward-dipping contacts does not match the gravitational data over the area. However, a body with inward-dipping contacts provides a better fit with the potential field data.

Using the magnetic data over the Pilanesberg, a 3D Voxi model is inverted for the body and internal structure (Figure 8). The Voxi model uses a block of cells in which each cell is a calculated density or susceptibility to make up a 3D model based on the Blakely theory. The solution defines the geometry of the Pilanesberg Complex to be reducing in size with depth and agrees with the 2D inward dipping model from the gravity data.

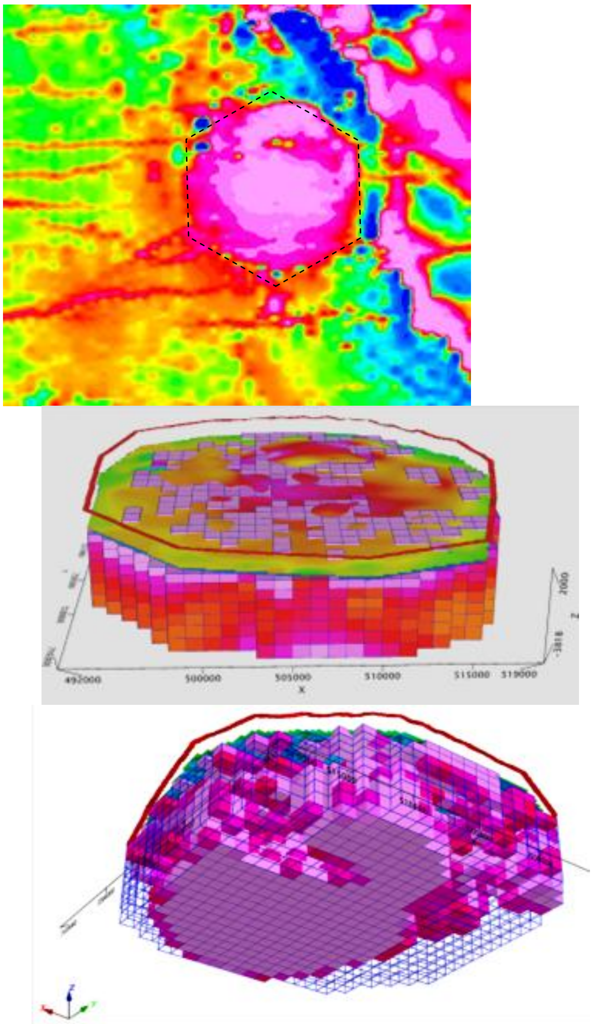

Figure 8. A) Magnetic data over the Pilanesberg complex indicated as a (325 nT) positive anomaly.
(B) A preliminary inversion of the Pilanesberg magnetic data into a 3D Voxi model using a 50x50 cell inversion.
(C) View from below showing how the Complex decreases in size from the surface to depth

2.5D modelling will be used to examine the Complex's horizontal strike and how it affects the 2D gravity profiled, while other 3D methods will be examined to achieve a model with a higher resolution.

CONCLUSIONS

The Pilanesberg Complex is the world largest alkaline intrusion and forms part of a suite of intrusions with ages ranging from 1450 to 1200 Ma including smaller clinopyroxene bodies in the Bushveld area and two magnetically reversed dyke swarms of similar age and composition.

The Pilanesberg Complex is examined with 2D gravity profiles to determine the emplacement relationship with the host rock. The 2D gravity models suggest an inward dipping model fits the gravity data best and concurs with the field relationships. The space problem of how the country rock accommodated such a large body and its shape, does not appear to be an issue as the intrusion of the Bushveld complex has fractured the country rock leave it weak enough to accommodate the intrusion as seen in the disturbed Magaliesburg rocks and Bushveld rocks to the west of the Pilanesberg. The inward dipping geometry of the Complex is supported by the preliminary 3D Voxi model which decreases in diameter with depth.

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